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Report number MDC-J5794

DISPLAY TECHNOLOGY:

AN ANNOTATED BIBLIOGRAPHY.

IRAD Technical Reports, Line Item No. DAC-26-72-R217

Revision date

Revision letter

Issue date December[redacted] 1973

Contract number

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DISPLAY TECHNOLOGY:

AN ANNOTATED BIBLIOGRAPHY

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December, 1973

ABSTRACT

This report reviews the recent literature on computer-driven information display techniques that have potential applications to military and commercial aircraft. An attempt was made to include survey documents or documents with broad descriptive content rather than an intensive analysis of a narrow aspect of a topic. With few exceptions, documents were limited to those published since 1965.

Major display techniques reviewed include cathode ray tubes, electroluminescent displays, light-emitting diodes, and liquid crystal displays.

Recommendations for an expanded follow-on research and development program are outlined.

KEYWORD DESCRIPTORS

Aircraft displays, flight instruments, visual, computer-driven displays, cathode ray tubes, electroluminescent, light-emitting diodes, liquid crystal displays, human factors.

ACKNOWLEDGMENT

This survey was conducted at the Douglas Aircraft Company under sponsorship of the Independent Research and Development Program (IRAD) of Douglas Aircraft Company.

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1. INTRODUCTION

1.1 Purpose

This document reports the progress made in the first phase of an IRAD project whose goal was to review recent developments in visual display technology and to identify potential applications to future aircraft.

Over the past 20 years, vast changes have occurred in the performance and handling characteristics of aircraft but cockpit display design has remained virtually static. The increasing complexity of high-performance aircraft has been matched by an increase in the number of moving pointers, tapes, and indicators used to display information to aircrews. As the improvements in performance capabilities resulted in increased flight speed, a vicious circle resulted. The time available to the pilot for scanning his instruments decreased while the number of instruments to be scanned kept increasing. However, this situation seems likely to change, gradually, in the future.

Recent technological advances in visual display techniques have been so great that the cockpit displays in future aircraft may be radically different from the present arrays of separate, single-purpose instruments. Many display capabilities that have been developed for FAA air traffic control, weapons control systems such as SAGE and BUIC, the Apollo program, and other systems are available for adaptation to commercial aircraft use. The digital inputs needed to drive many of these displays are also becoming available with the increased use of airborne electronic data processing systems made possible by the development of compact, high-speed computers using integrated circuits and large-scale integrated circuits. It is expected that there will be greater use of cathode ray tubes (CRT's) to combine several display functions in a single display, thereby reducing the number of specialized, discrete indicators. Also, light-emitting diodes and liquid crystal panels that are digitally addressed by a computer are expected to replace many of today's round dials, electromechanical, and mechanical instruments.

In the original project plan information obtained from an ongoing survey of the literature on display technology was to be analyzed and organized for convenient use by cockpit instrumentation design personnel. The project goal was reduced to the preparation of this bibliographical report to describe sources of information on display techniques.

1.2 Scope

The volume of information display literature is so large that stringent selection criteria were necessary to keep the bibliography within reasonable bounds for the convenience of users. An attempt was made to include survey documents or documents with broad descriptive content rather than an intensive analysis of a narrow aspect of a topic. With few exceptions, documents were limited to those published since 1965. Document sources included machine searches of DAC, NASA, and DDC data banks and manual searches of JANAIR bibliographies, NASA/STAR listings, current professional and trade journals, and references cited in documents.

1.3 Organization of Document

The general order of presentation is from broad categories to narrow categories of information. The broadest category is found in Section 2 where documents are described that review various types of display systems. Documents that survey various kinds of display techniques are cited in Section 3. In each of the subsequent sections on specific display techniques an attempt was made to describe first the documents of broadest scope. Other than this restriction there was no attempt to sequence the documents in any section by a temporal order or an order of merit.

1.4 Summary

Each of the many kinds of displays described in this document has so many variations that it is difficult to characterize specific display types for comparison with other types. It is not merely a problem of comparing apples

and oranges but of deciding what kinds of apples will be compared with what kinds of oranges. However, it is possible to identify general characteristics of various types of displays and to specify their typical values or ranges of values. In the following table some salient characteristics of five prominent display types are summarized. Values listed in the table are representative of the current state-of-the-art of this rapidly changing technology.

It is likely that the current trend toward increased use of cathode ray tubes in cockpits will continue for the next few years until CRT's are replaced by one or more of the other types of displays shown in the summary table. Among the advantages of CRT's are: versatility, proven technology, true colors, and high information display capacity. On the negative side, CRT's have large volume, require high voltages, and are more difficult to couple with solid-state circuits than light-emitting diodes or liquid crystals.

Light-emitting diodes have a fantastic life expectancy (up to 100 years for decay to half brightness) and relatively low voltage and power requirements but they have serious limitations for large scale panel use. LED's are suitable for displays consisting of a small number of elements, such as warning lights or alphanumeric indicators, but the cost of individual elements and control circuitry must be greatly reduced for them to be competitive with conventional CRT's.

As discrete displays, LED's have a strong competitor in liquid crystal displays. The latter have less life expectancy but they consume only one millionth the power of LED's. For cockpit use, liquid crystal displays have an advantage in being immume to washout due to bright sunlight but their relatively slow cycle times make them unlikely candidates as flat panel displays to replace CRT's. A more promising display for this purpose is the plasma cell.

Unlike other devices shown in the summary table one form of the plasma cell has inherent memory and does not require frequent refresh to emit a constant glow. Plasma cell costs are low in relation to LED's and LCD's. Projected

costs are as low as $0.01 per cell. This advantage is partly offset, however, by the cost of high voltage drive electronics required for plasma cells.

Of the five types of displays shown in the summary table, electroluminescent displays appear to have the least applicability for cockpit use because of their short life expectancies. They also require high a.c. drive voltages to obtain even moderate brightness levels.

The values and comments in the table pertain to the use of these devices in the cockpit. In other applications; e.g., in a ground installation where size and reliability are not critical, their relative merits might be quite different.

DISPLAY TECHNOLOGY SUMMARY TABLE

DISPLAY TYPE / CHARACTERISTICS	Cathode Ray Tube CRT	Plasma Cell	Light-Emitting Diode LED	Liquid Crystal Display LCD	A.C. Electroluminescent EL
Life Expectancy	7,000 to 20,000 hrs. Life depends on many variables such as phosphor characteristics and the luminance level of the display	5,000 to 50,000 hours.	100,000 to 1,000,000 hours	10,000 to 30,000 hrs. (a.c. operation) 3,000 hours (d.c. operation)	EL cell life varies inversely with frequency, but is independent of voltage, both of which affect luminance. Typical life: 1,000 hours for decay to half level from initial luminance of 15 fL
Drive Requirements	7,000 to 20,000 volts.	170 to 250 volts	2 - 3 volts 3 - 600 milliwatts	6 - 15 volts a.c. 15 - 30 volts d.c. 0.01 - 4 microwatts	50 - 500 volts.
Luminance	20 - 50 fL.	25 - 50 fL	50 fL.	LCD's do not emit light but act as light valves in passing reflected incident light or background generated light (transmissive mode). Typical contrast ratios: light scattering LCD - 20:1 field effect LCD - 40:1	15 fL Brightness varies with voltage, frequency, and age.
Color	Red, green, blue (primaries)	Neon-Orange, red	Red, green, yellow	Many combinations of colors of numeric and background are available.	Blue, green, orange, pink
Resolution	Typical: 30 to 125 lines per inch. The Northrop flat panel DIGISPLAY has a resolution of 50 dots per inch.	Gas panel display - GPD - up to 60 dots per inch.	Not yet suitable for large arrays.	Not yet suitable for large arrays	20-50 lines per inch
Depth of Tube or Array	6 - 20" The depth of CRT's approximates the face diameter except for very small tubes, which have greater proportionate depth, & very large tubes, which have less proportionate depth. Some flat panel CRT's are available, e.g., the Northrop DIGISPLAY which has a depth of 2".	1/2"	1/2"	1/2" In the transmissive mode, backlighting hardware will increase the depth.	1/16 - 1"
Display Panel Size	1/2" - 27" diameter. Larger sizes available on special order. The Northrop flat panel DIGISPLAY has a 3.5 x 5.5 inch display area. It can display a maximum of 512 characters in a 5 x 7 dot format.	8 1/2" x 8 1/2" This is the size of the DIGIVUE, which is the largest gas panel currently available. Can display a total of 2048 characters. (64 characters on each of 32 rows).	Not yet suitable for panel matrix use. LED's have a fast response but also have relatively large power requirements; e.g., a 1,000 x 1,000 array would require 5kW even if only 20% of the elements were lit. Maximum character size currently is 0.8" in height.	Not yet suitable for large-scale panel matrix use because long switching times make sequential scanning difficult. The maximum matrix currently available is 16 x 16 digits. Character size is not limited.	Display size is limited only by the capacity of production equipment. Individual characters as large as 10" in height have been produced. Slow switching times preclude EL use in large-scale panel matrices.
Switching Time	15 microsec.	20 microsec.	Nanosecond range.	Light scattering: 100 - 250 millisec Field effect: 30 millisec	100 - 200 millisec. when driven at 200 volts rms and 400 Hz
Advantages	Can display large amts of data. Flexible. Can display raw video, alphanumeric, or graphic data. Wide range of viewing areas. Can be helmet-mounted or panel-mounted. Gray scale and full color range available. Can be used with many types of input devices; e.g., light pen, track ball. Reliable. Can be ruggedized.	Flat panel. Low voltage (in relation to CRT). Rugged. Inherent memory available (DIGIVUE). No edge distortion. Fast switching. Suitable for display of moderate amounts of information (maximum of 2048 characters).	Flat panel. Long life. Low voltage. Thin profile. Rugged. Fast Switching. Suitable for displays consisting of a relatively small number of elements, such as alphanumeric indicators.	Flat panel. Very low power. Low voltage. Can be driven directly off metal oxide semiconductor (MOS) IC chip. Thin profile. Great flexibility in character size. Suitable for displays consisting of a relatively small number of elements, such as alphanumeric indicators.	Flat panel. Wide viewing angle. Rugged. Multi-color.
Disadvantages	High voltage. Large physical size. Edge distortion (with electrostatic deflection). Not directly compatible with solid state devices.	No gray scale currently available. No color currently available. High drive voltage required.	Not yet suitable for large matrices. Major breakthroughs in drive circuitry, power requirements, and cost are needed before large-scale LED matrices will be competitive with conventional CRT's. Limited character size.	Limited operating temperature range: 0 - 60°C. Not suitable for large-scale matrices. In reflective mode, contrast ratio is sharply reduced as viewing angle increases to 40°. Slow switching.	Limited luminance. Short life. High a.c. drive voltages. Not suitable for large-scale matrices which require rapid up-dating.

The display field is changing so rapidly that it is difficult to predict which media will eventually replace the electro-mechanical devices in current use. Competition remains keen because deficiencies of one mode may be corrected before the advantages of another mode are exploited fully. But, however difficult it is to predict specific usage, it is clear that radical changes in cockpit instrumentation are going to occur in the next decade. The justification for this statement goes beyond the changing state-of-the-art of display devices.

Marked progress in the entire avionics field has made the time ripe for a revolution in airborne displays. The primary impetus for change in the field of avionics has been the economies gained by the widespread use of electronic data processing (EDP) equipment in aircraft for equipment monitoring and control. EDP equipment proliferated as its reliability was increased, its weight, size, and power requirements were reduced, and its cost was reduced by major advances such as the use of solid state integrated circuits (IC). This expansion, in turn, made possible further savings through the use of large scale integrated (LSI) circuits. This entire trend has been completely consistent with the input requirements and capabilities of recently developed display techniques which use low-powered, digital inputs and require large-scale data processing support.

If it were not for the prior introduction of digital EDP equipment there would be little hope of introducing new cockpit display techniques because the new systems would have to bear the cost of analog-to-digital conversion and other data processing and storage functions. However, despite the availability of advanced display techniques and appropriate data processing capabilities that could be expanded to drive display hardware, cockpit instrumentation will not change markedly unless there is a clearly demonstrated need for change.

In the past, instruments were developed or taken off the shelf and added to cockpits as the need arose for additional information. Whether the devices were complex integrated attitude displays, or simple indicators of engine conditions or fuel status, they provided needed information in a somewhat

convenient format. They worked, and they continue to work in the same way in even the latest cockpit configurations. Why, then, should major changes be expected or sought?

One reason for changes in cockpit instrumentation pertains to safety. Serious problems still exist in displaying essential information during non-routine conditions or in emergency situations, particularly during take-off and landing. But even in the case of landing under fog or rain conditions, where some form of head-up display seems most appropriate, there has been only a slow, positive trend toward the addition of HUD systems in civil aircraft.

Another reason for introducing changes in cockpit display media derives from the potential cost savings that may be gained in several areas such as the following:

a) Computer-driven displays could reduce the number of display devices needed to present information during various phases of flight. They may be driven by multi-mode computer programs or by non-dedicated computers so that the multiple formats shown on a single screen can be the functional equivalent of several separate display devices. Aside from direct cost savings, reducing the number of separate displays reduces volume, weight, and power requirements. Pilot scanning time may also be reduced by the use of fewer displays and by properly integrated displays. Moveover, early definition and planning of display needs may greatly reduce the number of separate computers required throughout the aircraft bring major savings in total system costs.

b) The inherent flexibility of computer driven displays permits the design of more-completely standardized cockpits which can be made to serve a variety of special purposes by the use of specialized software rather than specialized hardware. Add-on features and options also may be provided without extensive hardware modifications.

c) It has been estimated that the use of microelectronics in the newer electronic display systems has increased their reliability by a factor of three. Some basic components have extremely high reliability as, e.g., light-emitting diodes that have reliability estimates as high as 10^6 hours. Also, computer-driven equipment may be automatically checked out by computer checkout and diagnostic programs. Computer software may also be checked by special programs. In addition, the use of multiple-function display equipment and modular computer programming with redundant storage of critical data provides an enormous redundant backup capability without the expense of using multiple hardware systems.

d) Computer-driven display systems with microelectronic IC and LSI components may provide maintenance cost savings through the use of diagnostic computer programs to locate defective components that may be replaced quickly by maintenance personnel having minimal training.

e) The use of electronic data processing equipment has reduced crew workload by such features as automatic flight control and navigational functions. There would be no need for a separate navigator position, even on over-water routes, if the necessary information were displayed to another crew member, e.g. the first officer. This could be accomplished without major hardware modifications if computer-driven multiple-purpose displays had been installed. The flight engineer's monitoring and diagnostic functions could be performed at the pilot positions if multiple-purpose displays were available to present the results of computer-processed equipment checks. This would not be feasible with the dedicated displays in current cockpits. A more detailed display problem easily overcome by computer graphic displays is exemplified by the DC-10 EGT(*) problem in which some displays need to be very sensitive in several different ranges. This requirement is extremely difficult to meet with electromechanical displays.

(*) engine temperature (EGT).

Savings and advantages such as those described above make it appear certain that the capabilities of digital processors will be expanded from automatic flight control functions and applied to new types of cockpit displays. Changes that have already begun with the introduction of an EADI(*), a PAFAM(**) display, an automatic navigation display, etc., suggest a brighter future for airborne display systems. Many special-purpose displays driven by special-purpose computers will be replaced by multiple-purpose displays which save space, reduce workload, and increase reliability through their redundancy. Centralized, modular data processors that drive the multiple-purpose displays will also contribute to economy and reliability.

In addition to such display system deficiencies as the lack of flexibility, reliability, or suitable integration of information, there may be misapplications of computer and display technology that seriously degrade the potential effectiveness of a system. This is especially true in new applications. When automation enters an established field there is a strong tendency to simply mechanize all tasks that were manual instead of seeking higher-order applications in which technology can be of maximum value.

One example of this tendency may be found in the conversion of the NORAD Combat Operations Center from a manual to a computer-based system (425-L). It was clearly desirable to replace a large manual, plot board with some form of computer-generated projection display system but there was some uncertainty concerning the handling of masses of other data in the form of hardcopy teletype messages that were reproduced and distributed to operators by runners. Each operational position received a flow of miscellaneous information that had to be examined for relevance for that position. Time was wasted in the reproduction of messages, in their delivery, and then later perusal by operators. Initial suggestions for improvement involved the use of TV cameras to scan incoming messages and display them on TV monitors at each operational position. This resolved the reproduction and delivery problems but did not give each operator the information he needed in a convenient format. This suggestion was not implemented in the final system.

(*) Electronic Attitude Director Indicator (EADI).

(**) Performance and Failure Assessment Monitor (PAFAM).

Another example of the degraded use of technology is found in the handling of USAF satellite data at the satellite test center (STC) at Sunnyvale about a decade ago. Mission data in the form of voice and digital messages were sent from tracking stations to the STC for interpretation by operational personnel. The digital data were entered directly into a computer, processed, and reproduced on a hardcopy printer. The printouts were in a tabular format suitable for later use by operations analysts but not suitable for real-time evaluation by operators who viewed the printouts on TV monitors. Voice messages were received directly by operators and also by personnel who used them and the computer listings to prepare mission progress charts, called "thermometer" displays. TV cameras scanned the charts and operators could view the crude images on their monitors. This process was very slow and the system worked only because it was largely by-passed by the two-way voice links between the STC operators and personnel at the tracking stations. After several years this system was up-graded by improved data processing and display techniques.

1.5 Recommendations for Implementation

From the above examples, it is apparent that the expanded use of advanced display technology should be accompanied by skillfully coordinated planning and research. Research has been extensive in some areas; e.g., the research on integrated displays sponsored by JANAIR, but in general past guidelines and standards for the design of individual electro-mechanical instruments are not applicable to the design of computer-driven displays if maximum benefits of airborne data processors are to be gained. In the past, information requirements for a task could be used to determine the characteristics of a display but the new technology offers a wide range of options that must be evaluated. Today, a display may determine the task rather than be determined by the task. For example, pointers are commonly used to supplement counters to aid in the detection of trends. The dial of such an instrument could be faithfully reproduced on a computer-driven cathode ray tube but this would not take advantage of the computer's potential capabilities. A new CRT format could be devised to ease the task of trend detection, or the task could be eliminated by the assignment of the function to the computer with only a qualitative in/out-of-tolerance indication given the pilot or flight engineer.

Research is needed to explore and evaluate the ways in which the new display media should be used and coordinated planning is needed to combine computer hardware, computer software, display hardware, and task characteristics into an effective total cockpit display system. A joint effort by several different design groups therefore is required to guide the development of future cockpit display systems. Required tasks include the following.

1.5.1 Survey display technology

The bibliography of display technology reported in this document should be revised and up-dated as a continuing effort. The display field is so extensive and is changing so rapidly that a centralized survey is needed to ensure that significant developments are not overlooked by all groups interested in aircraft display systems. The topics included in this initial survey were selected for their presumed relevance but future surveys would be based on actual user needs.

1.5.2 Compile technical data

During the course of the initial survey of display technology much technical data were found pertaining to the characteristics of various display techniques and human perceptual capacities. This information should be abstracted and compiled into convenient formats for use by all groups involved in display design. It should be up-dated periodically and modified in response to user evaluations.

1.5.3 Develop design concepts

Basic concepts or guidelines should be worked out for the evolutionary change of aircraft display systems. Essentially, these would be management evaluations of alternative plans developed by project personnel. These management decisions will be needed to narrow the scope of investigations to specific areas such as a particular future aircraft.

1.5.4 Identify candidate areas of change

This task would evaluate various display subsystems and select areas for concentrated investigation such as specific types of integrated displays, engine performance displays, maintenance displays, warning displays, galley displays, and passenger compartment displays.

1.5.5 Define display requirements

For each display area selected for investigation requirements should be defined to guide the selection and evaluation of potential display techniques. Possible types of requirements are: reliability, maintainability, ambient light conditions, vibrations, up-date rate, format, power, size, weight, viewing angles, quantity of data, color requirements, location, flexibility of usage, ambient temperature.

1.5.6 Identify potential applications

This task would evaluate the adequacy of various display techniques and devices to satisfy the previously identified requirements for selected display areas. This anlytical evaluation will identify devices of sufficient value for further consideration.

1.5.7 Develop application plans

Display devices found worthy of potential application would be exposed to further evaluation in relation to the context in which they will function. A proposed display may be considered in relation to a configuration of existing instruments or several proposed displays may be examined as a group.

1.5.8 Conduct tests and demonstrations

Potential display applications would be tested under simulated operational configurations to supplement previous analytical evaluations. These could range from quantitative performance tests of specific devices or techniques

being considered for near-term application to demonstrations of major cockpit changes proposed for long-term application.

2. SURVEYS OF OPERATIONAL DISPLAY SYSTEMS

Although the primary goal of this project is to identify display techniques that have potential cockpit applications other display systems are relevant to this topic. Surveys of entire display systems, rather than specific display techniques, illustrate the total system contexts in which display components function and the types of problems and requirements that may exist in a display system. A variety of display systems are described in the following documents.

2.1 NASA Visual Information Display Systems, A Survey. NASA SP-5049. Prepared by Auerbach Corporation, Philadelphia, Pa., 1968.

This document reviews a broad spectrum of display systems that have been developed by NASA and its contractors. After a very brief discussion of brightness, visual acuity, flicker and other human-dependent parameters, display hardware components are described in an excellent seventeen-page review of the state-of-the-art in 1968. Also described are the types of computer programs needed to support a large-scale display system.

Several manned spaceflight display systems are described, including systems for checkout, ground monitoring and control. Other systems described include: a display system for computer-aided instruction (PLATO); information storage and retrieval display systems for airline reservations and crime data; and simulation display systems for the Manned Spacecraft Center.

2.2 Howard, J. H. Electronic Information Display Systems for Management Detroit, American Data Processing, Inc., 1966.

Presents an overall view of the electronic information display field. In non-technical language, display equipment is reviewed and several management information display systems are described.

2.3 Hobbs, L. C. Display Applications and Technology. Proc. IEEE, 1966, 54 (12), 1970-1884.

Hobbs presents a brief review of display applications in command and control systems, management information systems, and on-line graphic systems for design automation and data retrieval. Prominent display technologies are also reviewed and evaluated in relation to small and large-screen applications.

3. SURVEYS OF DISPLAY TECHNIQUES

Several surveys of display techniques that have been published in the past few years are described in this section. They are convenient sources of information on the status of display technology but the user pays a price for this convenience. With the exception of conference proceedings, surveys tend to be less timely as they increase in scope. For example, the literature covered in a text may be several years older than the publication date of the book. Also, comprehensive coverage of topics limits the depth of coverage of individual types of displays. However, surveys of display techniques fulfill a need for information that is more specific than that found in surveys of display systems, but less detailed than the specific technique documents described in Sections 4.10.10.

3.1 Poole, H. H. Fundamentals of Display Systems. Washington: Spartan Books, 1966.

This book is a good introduction to display techniques. Cathode ray tube displays are emphasized but other techniques are also described. Cathode ray tube techniques are discussed in terms of the basic CRT, special purpose CRT's such as flat tubes and multigun tubes, and color CRT's. The phenomenon of luminescence is described and electroluminescent techniques are reviewed. Separate chapters are devoted to human engineering consideration and the optics of projection systems. These are also brief descriptions of future display techniques including laser displays, three-dimensional techniques, and projection techniques.

3.2 Luxemberg, H. R. and Kuehn, R. L., (Ed.) Display Systems Engineering. New York; McGraw-Hill Book Co., 1968.

Prior to a review of display techniques, this book lays a theoretical foundation in several chapters that include discussion of photometry, colorimetry, and optics. Cathode ray tube techniques are described in a separate chapter. Light valve, lasers, and electroluminescent devices are also reviewed.

3.3 NASA. Recent Advances in Display Media. A symposium held in Cambridge, Mass., September 19-27, 1967. NASA SP-159, 1968.

This document contains papers presented at the first NASA symposium on display media. The first three papers were written to highlight areas where further developments are required by citing deficiencies of existing media for advanced spacecraft, advanced commercial aircraft, and general aviation. The remaining papers provide state-of-the-art reviews of display media. Several of these papers are described below under specific display techniques.

3.4 Mahan, R. E. A State-of-the-Art Survey of the Data Display Field. BNWL-725, Pacific Northwest Laboratory, Richland, Washington, May 1968.

Presents brief review of black-and-white and color CRT's for console displays and describes a dozen type of large-screen display techniques. An appendix lists characteristics and costs of typical console display equipment being offered by manufacturers.

3.5 Gabelman, I. J. (Ed.) Displays for Command and Control Centers. AGARD-CP-23, July 1969.

Contains twenty papers that describe displays for military command, air traffic control, manned space flight, and air defense systems.

3.6 AGARD. Symposium on Guidance and Control Displays held in Paris, France, October 19-21, 1971. AGARD-CP-96, February 1972.

Contains papers on visual and workload criteria for guidance and control displays, the validation of display criteria, VTOL aircraft displays, and new display technology. Several of these papers are described below in sections on specific display topics.

3.7 Lowry, P. The Impact of Electronic Displays on Aircraft Control. Paper presented at AGARD conference on Advanced Control System Concepts, AGARD-CP-58, pp. 73-85, 1968.

This paper reviews some applications of electronic displays that can replace existing banks of electromechanical instruments. Most of these applications make use of direct or projected CRT displays. Advantages and primary data content are described for head-up displays and for head-down displays including vertical situation, horizontal situation, and tabular displays.

3.8 Kleiman, E. B. A Survey of Various Information Display Devices. NAVTRADEVCEN IH-74, May 1967.

Presents a brief review of electroluminescent and CRT displays and several projection type readout devices. Cost and physical characteristics of display equipment are included.

3.9 Crook, M. N., Raben, M. W., and Wade, E. A. Trends and Developments in Visual Displays. Tufts University Human Engineering Information and Analysis Service, HEIAS Rep. No. 107, December 1967.

Surveys developments in the areas of pictorial displays, literal displays, analog displays in aircraft and submarines, and projected symbolic displays. Also reviews human capacities that must be taken into account in the design of displays.

3.10 IEE Conference on Displays sponsored by the Intitution of Electrical Engineers and held at the University of Technology, Loughborough, England, 7-10 September 1971. IEE Conference Publication No. 80, 1971.

3.11 IEEE. 1970 IEEE Conference on Display Devices held in New York City, 2-3 December, 1970. IEEE 70C55-ED, 1970.

Some brief reviews of display techniques are included in the system survey documents described in paragraphs 2.1, 2.2, and 2.3 of this conference report.

4. CATHODE RAY TUBE (CRT) DISPLAYS

As the dominant type of electronic display device, the literature on CRT displays is voluminous. In little more than a decade, CRT applications have broadened from the fields of radar and television into computer interface displays, optical character recognition displays, medical electronics oscilloscopes and monitors, and avionics displays for aircraft and space vehicles. Several of these applications, e.g., head-up displays, integrated cockpit

displays, and human factors design considerations are described as separate topics in this report. Some general reviews of CRT technology and applications are described in this section.

4.1 Poole, H. H. Cathode Ray Tube Techniques. Part I of Fundamentals of Display Systems. Washington, Spartan Books, 1966.

Poole describes the basic cathode ray tube, special purpose tubes, and special color techniques. The basic CRT consists of three sections: an electron gun which forms and focuses an electron beam, a deflection system which positions the beam on a screen, and a phosphor screen that produces light of a desired intensity, persistence, and color when struck by the electron beam. CRT's may be classified as electrostatic or electromagnetic, depending upon the deflection method used. The electrostatic tube uses two sets of charged deflection plates to position the beam whereas the electromagnetic tube deflects the beam by means of fields produced by coils mounted on the sides of the tube. Magnetic deflection coils have a slower writing speed than the electrostatic tubes, due to the recovery time of the coils. This is not a problem in scanned applications such as television but for computer generated alphanumeric displays it is a serious limitation. Electrostatic tubes typically can write ten times faster than electromagnetic tubes. Poole discusses other advantages and disadvantages of the two types.

Conventional CRT tubes have depths approximately as long as their tube diameter. Flat tubes having a depth of only a few inches have been developed for applications where mounting depth is at a premium. Pool describes several versions of the flat CRT. Multigun tubes and direct printing tubes are also discussed.

The use of color for coding has been exclusively investigated in many display media but, until recently, CRT applications have been limited by the lack of satisfactory color CRT's. Poole identifies eleven color techniques and discusses four of them in some depth. No practical phosphor is available that can be made to change color under control of a signal so different phosphors must be used for each color, whether these phosphors are placed in dots, stripes, pyramids, layers or otherwise.

In the shadow mask tube three electron guns are arranged so that their guns converge on a single spot on the shadow mask. This mask is a perforated screen placed close to the screen and registered with it so that each hole in the mask coincide with a triad of three phosphor dots, one for each primary color. The gun alignment is such that phosphor dots of one color can be energized by a given electron beam. Typical 21-inch tubes employ about 600 lines resolution. Although shadow mask tubes are widely used for commercial television, they have a serious drawback for any other application, i.e., limited luminance. Approximately 15% of the total beam current reaches the phosphor screen, resulting in low light output. Because of this, and other factors, a figure of from 1 to 2.5 lumens per watt is all that is available with this tube, as compared to 30 or 35 lumens per watt for several monochrome phosphors.

Another type of color tube is the grid deflection tube invented by Dr. E. O. Lawrence. In its original form it used a single gun and a fine grid of parallel wires for the selection of color on a screen that consisted of thin parallel strips of phosphors of alternate colors. A more recent version of this tube uses three guns so that no color switching is necessary. The grid arrangement is used only for post-deflection focusing the three separate beams on three separate color phosphors. This type of color tube provides a brighter image than the shadow mask tube because over 85% of all electrons leaving each gun reach the phosphor screen. It is said to have six times the light output of the shadow mask tube. The grid deflection tube appears to be similar to the Trinitron tube recently introduced by Sony.

Beam penetration is a third color technique discussed by Poole. In this tube, which uses phosphor layers of various colors, beam penetration and hence color are controlled by changing the acceleration voltage. A single gun is used. Since one phosphor must be seen through the others, transparent phosphors are required. Recent applications of the penetration tube are described in the following paper.

4.2 Martin, A. F. Penetration Color Tubes are Enhancing Information Displays. Electronics, January 18, 1973, 155-160.

Martin describes the application of penetration color tubes in an air traffic control display that shows aircraft, labels, tracks, and air routes simultaneously and in different colors. In an airborne application he reports faster recognition than in a monochrome EADI display system. Martin also presents a comparison of shadow mask, Trinitron, and penetration tubes.

4.3 Asher, R. W. and Martin, H. Cathode-ray Devices, Chapter 8, 237-276 in Luxenberg, H. R. and Kuehn, R. L. (Ed.) Display Systems Engineering, New York: McGraw-Hill Book Company, 1968.

Reviews various types of CRT's (similar to Poole's survey described in paragraph 4.1). Also describes and tabulates the characteristics of CRT phosphors and presents a good review of methods of CRT symbol generation.

4.4 Davis, J. A. Recent Advances in Cathode-Ray-Tube Display Devices. Paper presented at NASA symposium on Recent Advances in Display Media held in Cambridge, Mass., September 19-27, 1967. NASA SP-159, 1968.

Reviews present state-of-the-art and current research in CRT technology. Describes: developments in luminescent materials (includes table of phosphor characteristics); resolution, brightness, and contrast techniques; developments in color CRT technology; and developments in projection techniques.

4.5 Dersch, W. C. and Johnson, R. T. Computer-Managed Display System for Advanced Commercial Transports. Paper presented at NASA symposium on Recent Advances in Display Media held in Cambridge, Mass., September 19-27, 1967. NASA SP-159, 1968.

Describes a display system designed as part of a study to evaluate applications for automation in commercial air transport operations. The goal of the display management concept was to control by computer those routine functions that can

be preplanned and that do not require pilot judgment. Multimode CRT's are used to furnish the pilot only usable information. With his permission, the display panel is automatically configured to the most efficient layout.

4.6 Seats, P. The Cathode Ray Tube-A Review of Current Technology and Future Trends. Paper presented at 1970 IEEE Conference on Display Devices held in New York City, December 2-3, 1970.

Discusses new and improved phosphors and the current status of color screen techniques.

4.7 Corbin, H. S. A Survey of CRT Display Consoles, Control Engineering, December 1965, 77-83.

Presents data on 35 commercially available CRT consoles, discusses their features, and gives some pointers on console selection.

4.8 Lewin, M. H. An Introduction to Computer Graphic Terminals, Proceedings of the IEEE, September 1967, 55 (9), 1544-1552.

Discusses display refresh and character generation techniques in typical computer-driven CRT displays. Input devices are described and the software structure for one possible graphic processing system is described.

4.9 Machover, C. Interactive CRT Terminal Selection. SID Journal, 1972. November-December, p. 10-17, 22.

This paper describes briefly eight types of commercially available CRT terminals and discusses 19 performance factors than should be taken into consideration in the selection of interactive CRT terminals.

4.10 Jacobs, L. D. CRT Graphics Consoles - An Aid to their Selection. RADC-TR-71-61, November 1971. Rome Air Development Center, USAF Systems Command, Griffin AFB, New York.

Provides an excellent introduction to the hardware and software technology involved in computer-generated CRT display devices. Describes basic capabilities, functions, and relative merits of various CRT display techniques. A listing of current (as of 1 October 1970) specific displays, capabilities, and costs is given in an appendix.

5. A. C. ELECTROLUMINESCENT (EL) DISPLAYS

During the past decade there has been increasing interest in the use of electroluminescent (EL) displays to replace incandescent lamps in cockpit instruments. These two phenomena differ in that incandescence makes use of heat for the generation of light whereas the basic phenomenon of electroluminescence, i. e., luminescence, involves the emission of light without the employment of heat. There are many types of luminescence, e.g. bioluminescence, or the emission of light by biological systems, and photoluminescence which is the property that some materials have for emitting light of one frequency when light of another frequency falls upon them. The latter phenomenon is referred as fluorescence when light is emitted and persists only as long as the stimulating radiation is continued. Common applications include fluorescent paints and fluorescent lighting.

Some light-emitting materials or phosphors emit light following exposure and removal of incident radiation. This type of luminescence is called phosphorescence and is an important property for display applications. When the incident energy is in the form of an electron beam, the process of phosphorescence is known as cathodoluminescence which is the method of light production in the cathode ray tube. A second type of phosphorescence, which occurs when a phosphor emits light under the influence of an electrical field, is known as electroluminescence. There are two general types of electroluminescence, a. c. or d. c., depending on whether the field in alternating or direct current. Selected literature on a.c. EL displays is described in this section. D. C. EL literature is described in the following section.

5.1 Poole, H. H. Fundamentals of Display Systems. Washington: Spartan Books, 1966.

Poole's description of the phenomenon of luminescence (Chap. 17, 321-346) was the primary source of the background information presented above. He describes some EL techniques and applications in Chapter 7, 109-117 in conjunction with large-screen display techniques.

5.2 Berthold, W. Electroluminescence Display Devices. Paper presented at AGARD symposium on Advanced Technique for Aerospace Surveillance held in Milan, Italy, September 4-7, 1967. AGARD CP-29, 1968.

Reviews the principle of operation of EL and describes several applications including: one-dimensional or thermometer-type displays; symbol display units; a crossed-grid technique for two-dimensional displays; large screen displays made of smaller units; and multicolor screen displays.

5.3 Peterson, C. J. Solid State Display Techniques. USAF: AFFDL-TR-66-123. Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, October 1966.

Describes the AF Flight Dynamics Laboratory program for the development of EL techniques for cockpit displays. Advantages over electromechanical devices include digital control, improved reliability, automatic scale factor variability, minimized weight, reduced size and power requirements, and reduction of display costs.

5.4 Petertyl, S. V., Fuller, P. R., and Wysocki, C. A. Development of High Contrast Electroluminescent Displays. USAF: AFFDL-TR-66-185, Air Force Flight Dynamics Laboratory, Wright Patterson AFB, Ohio, March 1967.

Describe the development of techniques to greatly improve the contrast and visibility of EL displays. The use of a black-appearing high-contrast filter and anti-reflection coatings improved display visibility while allowing a large reduction in the display brightness needed for daylight cockpit EL applications.

5.5 Forst, J. S. and Wright, R. H. Functional Evaluation of Electroluminescent Pictorial Status Displays. C7-2191-301. Avionetics Division, North American Rockwell Corporation, September, 1967.

Early types of EL displays in operational use generally duplicated conventional types of presentation. Thus the EL bar graph essentially duplicates its electromechanical counterpart, while the mosaic or crossed-grid approximates the CRT. In this study, EL pictorial status displays were designed to make maximum use of the inherent flexibility of EL technology. Displays for the presentation of aircraft fuel quantity information, including flow, were developed by considering the basic information requirements of the system and the potential of electroluminescence to meet these requirements. EL display encodement techniques, together with their advantages and limitations, were also studied.

5.6 Arai, H., et al. EL Panel Display. Paper presented at 1970 IEEE Conference on Display Devices held in New York City, December 2-3, 1970.

Describes a cross grid matrix type of EL panel capable of displaying bright moving pictures from video signals fed from a TV receiver. High brightness was achieved with relatively low voltage and power. The device is still under development but the authors hope that this type of EL panel may be able to replace the CRT in the near future.

5.7 Elson, B. M. Tricolor Display Panels Developed. Aviation Week and Space Technology, January 17, 1972, 54-55.

Elson reports the development of three-color EL display panels that may be fitted together to form computer-controlled displays for advanced command and control applications. Possible formats range from 16 inch square displays for aircraft to 15 ft. square wall displays for aircraft carrier command facilities. A digitally addressed x-y format eliminates the need for digital-to-analog conversion that is required in many CRT displays. One special feature of this panel, developed by A. T. Schjeldahl Co. for the Navy, is a latching mode in which a photoconductive (photoelectric) element converts the momentary outputs

of the addressable matrix into a continuous display. Also, elements in a red, green, and blue triad can be addressed individually to produce a three-color display, or in combinations to produce a total of six colors plus white.

5.8 Reynolds, H. N. The Visual Effects of Exposure to Electroluminescent Instrument Lighting. Human Factors, 1971, 13(1), 29-40.

Reynolds investigated the effects of exposure to an EL aircraft instrument panel on dark-adapted vision. Several colors of EL lighting were compared with aviation red incandescent lighting. He fcund that exposure to green EL, which is the most efficient phosphor and the most common hue for EL lamps, produced an increase in acuity threshold larger than any of the other colors tested. However, although most threshold differences between colors were statistically significant, the absolute differences in visual sensitivity were quite small. The evidence indicates that the effects of illumination color on visual acuity or legibility are, at most, very slight.

6. LIGHT-EMITTING DIODE (LED) DISPLAYS

This type of display is described in the literature under several different names. In addition to the most common designation, LED, other names are d. c. electroluminescence, carrier injection electroluminescence, and electroluminescent diodes.

D. C. Electroluminescence consists of the light emission created by the action of a direct field upon crystals. Although this type of EL was first reported in 1923, its development has lagged behind that of a. c. EL, which was first reported in 1936. Most d. c. EL studies have been on thin films, rather than the powder material used in a. c. EL, since the crystals must be contact with the conducting electrodes to allow current injection to occur. The following papers are recent surveys of the current status of LED display technology.

6.1 Thomas, D. G. Light-Emitting Diodes. Paper presented at 1970 IEEE Conference on Display Devices held in New York City, December 2-3, 1970.

This paper reviews the technology of light-emitting diodes and discusses problems of production and practical application. Among the five semiconductor materials that emit visible radiation gallium arsenide phosphide, GaAsP, currently dominates the commercial display field. It has efficient light emission and its light does not spread because of strong absorption characteristics.

Four of the available LED materials emit only red light. The fifth, galliium phosphide, GaP, can emit red, yellow, and green light and is emphasized by Thomas because of its potential commercial importance.

Light emitting structures can also be made using diodes which emit invisible radiation. In one version of this new technology, gallium arsenide is used to emit infrared which then activates special phosphors to produce visible light. These devices are not yet very efficient but they are important because they may produce blue light with a suitable choice of phosphor, whereas practical LEDS cannot emit blue light.

6.2 Peaker, A. R. Light-Emitting Diodes and Diode Arrays Using Gallium Phosphide. Paper presented at the Conference on Displays sponsored by the Institution of Electrical Engineers and held at the University of Technology, Loughborough, England, September 7-10, 1971.

In agreement with the previous paper by Thomas, Peaker emphasizes the potential importance of gallium phosphide as a source of both red and green light in individual lamps or in monolithic arrays in the near future.

6.3 Berg, A. A. and Dean, P. J. Light-Emitting Diodes. Proceedings of the IEEE, 1972, 60(2), 156-223.

This major paper (68 pages, 90 figures, 350 references) provides comprehensive coverage of the complex topic of light-emitting diodes. It concentrates on

LED technology rather than applications. A section on photometry describes the phometric quantities of luminous flux, illuminance, luminance intensity, luminous flux, and lumininance in conjunction with related radiometric quantities. The elements of vision are treated briefly. Another section reviews background concepts of semiconductor physics and discusses injection mechanisms. Light generation efficiency in various materials is discussed in depth and mechanisms of EL degradation are described. Some problems in the application of LED's as single indicator lights and symbolic display are discussed in a concluding section on applications.

6.4 Pucilowski, J. J. The Effectiveness of Light-Emitting Diodes as Display-Device Elements. Proceedings of the Society for Information Display, 1971, 12(1), First Quarter, 1-5.

Reviews study of LED's to evaluate their merit for military display use. Prices are falling rapidly but in 1971 individual diodes cost about $1.00. Thus, an array of 200 x 200 individual LED's would cost about $40,000 without circuitry or packaging. They have an extremely long lifetime according to some tests. Step-stress testing has resulted in a figure of over 10^6 hours (one-hundred years) for decay to half brightness for some LED's. They also have turn-on/turn-off times in the nanosecond range and have high resistance to degradation caused by vibration and environment. Pucilowski gives brightness versus voltage and current curves, light-output contours, life test data, and spectral outputs. He considers discrete LED's well suited for displays consisting of a relatively small number of elements, such as warning indicators or alphanumeric and graphic type indicators.

6.5 Lea, L. H. Current Trends and Future Developments in Optoelectronic Displays. Electronic Engineering, March 1971, 34-36.

This brief paper discusses the development and some applications of LED's. Phosphor-type a. c. EL devices have several undesirable characteristics, e.g., they are short-lived, not particularly bright, and require a high voltage and an a. c. power supply. These requirements are not compatible with integrated-circuit and transistor technology, so the LED is clearly superior for many applications. Lea discusses weaknesses of LED's for use in matrix displays.

Cost, power requirements, and the lack of blue diodes at the present time rule out the use of light-emitting diodes to produce a flat television display. The use of LED's in a hand-held probe or in head-mounted displays that keep the data within the field of vision regardless of the position of the observer are promising areas of development. Improvement in efficiency will provide better performance in high-ambient-light conditions and the availability of different colors will increase the versatility of LED devices.

6.6 Anon. What's New in Small Displays. IEEE Spectrum, November, 1972, 19-24.

This paper is a brief, non-technical review of the characteristics and current applications of LED's and several other types of small display devices including liquid crystal and plasma displays (described in the following two sections). LED's currently are more widely used than other devices in pocket and desk-top calculators. They are also being used in electronic digital wristwatches where they have the advantage of being readable in total darkness although they may be hard to read in bright sunlight. Applications are expected to develop in the automotive industry. Advantages of LED devices include reliability, long life, compatibility with integrated circuits, fast response time, operation over a wide range of temperatures, and high contrast ratios. Some disadvantages include high price compared with other displays, limited character size, and a tendency to cause discomfort for some viewers because the human eye has poor response to red light in the range over which they emit.

6.7 USAF-FDL Light-Emitting Diode Arrays. Control Display Progress. Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, July, 1972.

Describes some advantages of using LED arrays to form flexible format displays. LED's require only 2.9 to 3.3 volts which makes them compatible with large-scale integrated circuitry. They have a lifetime in excess of one million hours, nanosecond turn-on, and hold promise of total color capability. In addition, all cockpits can be standardized to LED matrix displays and thus save on procurement cost, logistics problems, and maintenance problems.

7. LIQUID CRYSTAL DISPLAYS (LCD's)

Although this is a relatively new field of investigation developments and applications have come quickly. LCD's are actively competing with LED devices for the pocket and desktop calculator market. North American Rockwell Microelectronics Company is currently producing liquid crystal displays for more than 200,000 calculators for Lloyd's Electronics and Sears. Its extremely low power requirements make LCD's suitable for use in digital wristwatches although they have one limitation for this application: they cannot be read in darkness since they are not light emitting and depend on ambient light. However, this characteristic makes LCD's very effective under the high ambient light conditions of a cockpit. Some of the rather limited number of documents in this field are described below.

7.1 Sprow, E. E. Liquid Crystal Displays Brighten. Machine Design, September 7, 1972, 112-117.

Presents a non-technical description of the various types of LCD's. Liquid crystals are derivatives of cholesterol that display many of the optical properties of solid crystals while in a liquid state. They can be optically oriented by electrical fields or thermal radiation.

Two major classes of liquid crystals are the cholesterics and the nematics. Cholesterics change color with temperature or electric field and are used in thermal mapping. The nematic liquid crystals (NLC's) are in widespread use as numeric display devices. There are two kinds of nematics - light scattering and field effect.

A light scattering nematic crystal in its quiescent state is clear and passes light. As the voltage gradient is increased across the film, discontinuities form that scatter light and the active area appears brighter than normal. The display can be either reflective (with a mirror backing) or transmissive (with backlighting). In either case, the numbers are white with a brightness that varies with room ambient light intensity.

Field-effect nematic crystals rotate incident light 90° when in the quiescent state (3 volts). With higher voltage (6 v.) no rotation occurs. If the crystals are placed between polarizers the resulting display may allow light to pass or may block it depending on the axis of the polarizers and the state of the crystals. By the use of either a mirror or backlighting the display may be reflective or transmissive, as in light scattering nematics. Field-effect nematics have a faster response and require less energy than light scattering nematics.

Sprow contrasts the operating characteristics of the two types of nematic liquid crystal displays with light emitting diodes in terms of life, power requirements, size, and legibility.

7.2 Creagh, L. T., Kmetz, A. R., and Reynolds, R. A. Performance Characteristics of Nematic Liquid Crystal Display Devices. Paper presented at 1970 IEEE Conference on Display Devices held in New York City, December 2-3, 1970.

This paper describes light scattering nematic liquid crystal displays under development by Texas Instruments, Incorporated. Both transmissive and reflective types are discussed. Transmissive cells, illuminated from the rear by a light source which is hidden from the viewer, are transparent except where excited. They may be used as electrically alterable overlays for other displays (maps, CRT's). Reflective nematic liquid crystal displays have mirror-bright metal back electrodes; the whole display need be no thicker than the glass sandwich itself. Electrically activated segments achieve good control by scattering light which otherwise would be specularly reflected by the back electrode away from the observer. In this configuration there is no need to supply power for illumination since the display operates from the incident ambient light. Also, the contrast ratio of such reflective displays is independent of the brightness of the ambient light; thus, these displays are immune to "washout" even in direct sunlight. Contrast ratios and response times are plotted against cell thickness and temperature for a proprietary panel (N-014). Operating lifetime of continuously dc biased displays using

N-014 material were found to be in excess of 1000 hours. Some tests indicated that display cells lasted much longer with ac drive. An operating lifetime scale factor around 100X was typical when comparing results with dc and ac drive.

7.3 Gurtler, R. W. and Maze, C. Liquid Crystal Displays, IEEE Spectrum, November, 1972, 25-29.

Describes the characteristics of transmissive and reflective modes of nematic liquid crystals. Content is similar to that of Sprow (7.1 above).

8. PLASMA DISPLAYS

The plasma display panel was invented in 1966 at the University of Illinois for the purpose of displaying digital information directly from a computer and retaining the information in a large number of terminals. It is in strong competition with LED's and LCD's for the display of digital data. The typical plasma display panel is an array of gas discharge cells that are separated from exciting electrodes by thin dielectric sheets. Except when information is changed, every cell is excited by an ac voltage that is of insufficient peak value to cause discharge, so that an unlit cell remains unlit. If a pulse is added to this voltage on the rising part of the waveform, the gas in the cell breaks down (i.e. ionizes). The ions formed move to the cell walls, creating a voltage opposed to the applied voltage, causing the discharge to quench. This process takes place in about 40 nsec. When the applied voltage changes sign, the wall charge adds to it, causing a breakdown to occur in the negative half cycle without the application of a pulse. In the "ON" state, the cell supports one pulsed discharge in each half cycle of the exciting signal and it emits light in bursts, one for each discharge in the series. This process continues until a pulse is applied to cancel the wall charge. It is thus a bistable device. The light pulses that are emitted appear as a steady glow. The operation and current status of plasma displays are described more completely in the following papers.

8.1 Slottow, H. G. The Plasma Display Panel - Principles and Prospects. Paper presented at the 1970 IEEE Conference on Display Devices held in New York City, December 2-3, 1970.

In this paper, Slottow, one of the inventors of the device, gives an excellent description of the operation of the plasma display panel technique. (The introductory comments above were taken largely from this paper.) He also describes extensions to the basic technique. Information can be transferred directly to the display by optical or electrostatic means, it can be read from the display by a computer, both optically and electrically, and it can be imaged in hard copy through photo-excitation of sensitized paper. Color beyond that of the gas discharge itself can be provided by stimulation of phosphors that are deposited on the dielectric surfaces. Finally, the display panel presents a screen on which an image projected from a photographic slide, selected by a computer, merges with the digital information generated by the computer.

8.2 Willson, R. H. The Plasma Display - A Digitally Controllable High Brightness Display with an Inherent Memory. Paper presented at NASA symposium on Recent Advances in Display Media held in Cambridge, Mass., September 19-27, 1967. NASA SP-159, 1968.

Describes the history of the development of plasma displays, cell construction, an explanation of the bistable characteristic, techniques for writing and erasing, current status, and problem areas. The content of this paper is quite similar to Slottow's (8.1), with the exception of Willson's discussion of input methods. Many techniques are possible for inputting data into a plasma display. The most straightforward method is to control the voltage on each row and column electrode independently. A second method is to drive the lines in parallel with a single sustaining voltage source and to add pulses to appropriate lines. Both methods are discussed by Willson.

8.3 Titchmarsh, J. G. The A. C. Plasma Panel. Paper presented at the Conference on Displays sponsored by the Institution of Electrical Engineers and held at the University of Technology, Loughborough, England, September 7-10, 1971.

Presents a brief review of the construction, principles of operation, and operating characteristics of a gas discharge matrix.

9. MISCELLANEOUS DISPLAY TECHNIQUES

In addition to the major techniques described above there are many less prominent techniques that may satisfy special purposes. Some of these are described in the following papers.

9.1 Grafstein, D., Burkowski, R. P., Kornblau, M., and Flint, W. L. Thermochromic Displays. Paper presented at NASA symposium on Recent Advances in Display Media held in Cambridge, Mass., September 19-27, 1967. NASA SP-159, 1968.

Thermochromics are materials that undergo a color change when they are heated above a certain temperature, called the transition temperature, and revert back to their original color when cooled. For information display applications, the color changes must be fast and result in a sharp contrast of one color on another. This paper describes tests of the use of thermochromic in a CRT, both or a substitute for the phosphor and in conjunction with the phosphor. Both conditions resulted in thermochromic behavior but much work remains before the technique can be used in a practical CRT.

9.2 Sinnott, R. C. Magnetic Display Devices Paper presented at NASA symposium on Recent Advances in Display Media held in Cambridge, Mass., September 19-27, 1967. NASA SP-159, 1968.

Describes several magnetic display devices in common use, e. g. the d'arsonval moving coil galvanometer and the ratcheting drum display, and some that are in early stages of development. Progress in the development of magnetic display

devices has fallen far behind other display technologies but Sinnott suggests that there may be a resurgence of interest in the field because of their compatibility with solid-state devices.

9.3 Rice, P. Electrostatic Displays. Paper presented at NASA symposium on Recent Advances in Display Media held in Cambridge, Mass., September 19-27, 1967. NASA SP-159, 1968.

Describes several methods of generating dynamic displays by means of electrostatic forces. The most common application is electrostatic printing such as in office copiers in which an image of a document is projected onto a precharged selenium drum, draining charge away in the illuminated area. Pigmented particles which cling to the drum regions of high field gradient are transferred to a sheet of paper by contact. Another application is based on the deformation of a plastic or oil film in response to a charge pattern deposited by a CRT electron beam. The deformed plastic permits light to be transmitted through an optical system and projected area screen. Variations of this technique are referred to as thermoplastic displays, thermoplastic light-valve displays, or oil-film light valves. As an alternative to these projection systems, a third electrostatic display technique produces images that can be seen by direct viewing in ambient light. An array of lightweight plates, as small as one-sixteenth inch on a side, are hinged about this horizontal axis so that either side may be exposed by means of an XY array of address wires. The forces responsible for the movement of the plates are the same as those that cause the plates of the familiar goldleaf electroscope to diverge. Patterns may be produced if the plates are painted, for example, black on one side and white on the other.

9.4 Kennedy, D. W., Grauling, C. R., Devaney, A. J., and Wright, R.D. A Survey of Laser Display. Paper presented at NASA symposium on Recent Advances in Display Media held in Cambridge, Mass., September 19-27, 1967. NASA SP-159, 1968.

This paper discusses two basic categories of laser display systems: those based on moving (scanned) laser beams and those which use the concepts of

holography. The latter category is described in the following section under the topic of three-dimensional displays (10.1.4, 10.1.5, 10.1.6).

Scanned laser beam displays use basic techniques from the CRT field, but a laser beam and appropriate scanning devices are substituted for the CRT and its deflection system. The major problems are in refining techniques to manipulate the laser beam and to modulate its intensity although this methology is in an advanced state of development due to the fact that flying spot display techniques are well known from industrial CRT experience. Deflection techniques and suitable types of lasers are discussed and three existing display applications are described. Scanning laser displays have the potential for substantial improvement over conventional CRT's. Ultimately, color-scanning laser displays will be developed to the point where they will replace the CRT in many flying spot applications. They offer greater brightness and greater resolution, and the display beam need not be in a vacuum. In addition, a scanning laser system can provide a very large display screen for multiple viewing with a practical degree of brightness and resolution.

10. MISCELLANEOUS DISPLAY APPLICATIONS

Many of the display techniques that have been described in preceding sections have been used in a variety of applications. This section will review some of the literature on a few prominent types of display applications.

10.1 Three-Dimensional (3-D) Displays

10.1.1 Tilton, H. B. Principles of 3-D CRT Displays. Control Engineering, February 1966, 74-78.

Tilton describes an approach to the problem of representing three-dimensional perceptual cues on the two-dimensional surface of a CRT. A computer performs coordinate transformations to simulate four depth cues to provide depth perception. For example, the oscilloscope is equipped with a tracking device which follows the observer as he moves and causes the CRT image to be modified in such a way that he can "look around" the scene.

10.1.2 Barmack, J. E. and Sinaiko, H. W. Human Factors Problems in Computer-Generated Graphic Displays. Three-Dimensional Considerations. Study S-234, 24-30. Institute for Defense Analysis, Washington, D.C., April 1966.

This paper briefly describes the principle of depth perception and some techniques for generating illusory 3-D displays. There are no behavioral data that show quantitatively any advantage of 3-D displays when used in complex operational real-time situations, e.g. predicting impact points, or in target identification.

10.1.3 Lewis, J. D. and Walling, G. P. A True 3-D or Flat 2-D Display. Paper presented at AGARD conference on Guidance and Control Displays held in Paris, France, October 19-21, 1971. AGARD-CP-96, October 1971.

Describes a new display principle which promises to make available a true 3-D display or a multi-color, solid-state, flat-panal display. The basic principle employs a pair of light beams intersecting in a display volume. For a 3-D display the volume is approximately a cube and the light beams enter the volume through one or two of its faces. For a 2-D display, the volume has very little depth, perhaps a centimeter or less, and the light beams enter through one or two of the thin edges. The volume is a transparent material that will fluoresce at the point of intersection of the light beams. The phenomenon employed is the stepwise excitation of fluorescence whereby a single light beam will excite the material to a certain level but a fluorescent spot will be generated only at the intersection of two beams.

10.1.4 Jacobson, A. D. Requirements for Holographic Displays. Information Display, November/December, 1970.

Jacobson states that the hologram process provides the most effective means presently known for producing true 3-D imagery. By true 3-D imagery he means imagery containing not only stereoscopic information but also perspective information, parallex information, and selective focus information about the subject. He describes the basic principles of holography, some of its requirements and applications. Some potential applications are: the hologram analog

of the conventional still photograph for such uses as art, science, technology, and advertising; hologram motion pictures; holographic TV; and computer generated holograms. In the last application, the hologram is synthesized by calculation rather than being formed with light. The procedure is to store the "subject" numerically in a computer and then calculate, using physical optics, what the hologram exposure would be at the hologram plane for the given subject plus a computer generated reference beam. This output from the computer could be used to form a physical hologram on an appropriate photorecording material.

Jacobson describes an application proposed by IBM to aid pilots in landing on aircraft carriers. In this system an image of the carrier is recorded on a hologram and the holographic image is presented to the pilot on a head-up display. As the relationship between the aircraft and the carrier changes the holographic image is automatically varied to show visually this changing perspective.

10.1.5 Kennedy, D. W., Grauling, C. R., Devaney, A. J., and Wright, R. D. Holographic Displays. In A Survey of Laser Display presented at NASA symposium on Recent Advances in Display Media held in Cambridge, Mass., September 19-27, 1967. NASA SP-159, 1968.

The content of this paper is essentially similar to Jacobsen's paper described above (10.1.4). Properties of holograms are described and some applications are discussed. One potential application is the use of a holographic head-up display for all-weather landing. A small onboard computer would drive the display using data from the aircraft's instruments and ground control. The view would be reflected from the windshield. The update rate could be rapid enough to give the pilot an effectively continuous display. A similar display could be used in a flight simulator to give a realistic feel of flight.

10.1.6 Parker, J. Laser Holography, Chapter 11, 392-432 in Luxemberg, H. R. and Kuehn, R. L. (Ed.) Display Systems Engineering, New York: McGraw-Hill Book Company, 1968.

Presents a basic description of the holographic process, its potential uses and its limitations.

10.2 Head-Up Displays (HUD's)

A head-up display is a device that presents information about the actual and desired situation of an aircraft is such a way that the pilot can view both the display and the natural external scene at the same time. The name derives from the fact that the display is visible to the pilot while he is "head-up", looking out of the cockpit. Head-up displays have been under investigation for nearly 20 years and an enormous body of literature has been produced. Fortunately, some recent reviews are available to provide an introduction to this topic. Three of these are described briefly below together with a few of Mike Naish's HUD publications and a paper on HUD optics by Vern Hamilton and Joel Benson of DAC.

10.2.1 Smith, J. H. The Impact of Advancing Technology on the Evolution of Electronic Head-Up Display Systems. Paper presented at AGARD conference on Guidance and Control Displays held in Paris, France, October 19-21, 1971. AGARD-CP-96, October, 1971.

This paper briefly outlines the history of HUD systems as applied to military aircraft with primary emphasis on engineering and hardware aspects. HUD components are described. The development of the waveform generator or electronics unit through four stages, i.e., thermionic vacuum tubes, transistors, integrated circuits, and large-scale integrated circuits, as it evolved from an analogue to a digital computer.

10.2.2 Sones, J. H. Head-Up Display Systems in Modern Aircraft. Paper presented at the Conference on Displays sponsored by the Institution of Electrical Engineers and held at the University of Technology, Loughborough, England, September 7-10, 1971.

Sones presents a very brief overview of a typical HUD system including its principle of operation and the form or symbology of the display. Some possible applications to civil aircraft are discussed.

10.2.3 Jenney, L. L., Malone, T. B., and Schweickert, G. A. Head-Up Displays A Study of Their Applicability in Civil Aviation. NASA study N71-19752 conducted by the Matrix Research Division of URS Systems Corporation, Falls Church, Va., 8 January 1971.

Basically, this is an analytic study of the research literature on the subject of aircraft operating problems and the head-up display. Some of the topics included in this broad survey are: operational problems in approach and landing; the pilot's visual task; visual aids; the role of the head-up display; and technological and human factors problems that must be solved before the HUD can gain final acceptance in civil aviation.

10.2.4 Naish, J. M. Properties and Design of the Head-Up Display (HUD). MDC-J1409, Douglas Aircraft Company, Long Beach, California, February 1970.

This paper deals with practical aspects of different classes of symbols and shows that pictorial or real-world symbols are almost necessarily excluded from HUD.

10.2.5 Naish, J. M. Flight Tests of the Head-Up Display (HUD) in DC-9-20 Ship 382, November 1968 - January 1969. MDC-J0878 Douglas Aircraft Company, Report Long Beach, California, September, 1970.

This report is concerned with developments in head-up presentation affecting its application to civil aviation. Principles of organizing display format are discussed in terms of format position, simplicity, symbol position, and other variables that influence the access and interpretation of information and the movement of attention between display and forward views. The dual observation of display and forward views as well as learning effects were studied in demonstration flights. This work opens the way for further investigation and comparison of human and automatic tracking performance for accuracy, variability and freedom from disorientation, with special relevance to all-weather approaches.

10.2.6 Naish, J. M. Control Information in Visual Flight. Douglas Aicraft Company, DP 5921, Long Beach, California, June 1971.

The purpose of this study was to determine how precisely a pilot can estimate the movements of his vehicle, and thus exercise control, during an unaided visual approach. An attempt was made to quantify some of the visual mechanisms involved in flight. The study also deals with the shortcomings of a runway symbol as a source of information for central purposes.

10.2.7 Naish, J. M. Information Transfer in All-Weather Operations. Shell Aviation News, Number 396, 1971, 8-10.

This paper deals with the concepts of balanced information flow and the improvement in efficiency of acquiring information due to conformities of position and form. It also discusses the integration of different classes of information for monitoring purposes.

10.2.8 Naish, J. M. Head-Up Display for the Visual Approach. DP 6033 Douglas Aircraft Company, Long Beach, California, May 1972.

Discusses information requirements for a superimposed display for the visual approach. There are two basic methods of using HUD in the visual approach to provide information in the vertical control plane. A symbol depressed from the true horizon by a constant angle can be used to show displacement from a given flight path. A symbol displaced from aircraft datum by the angle of attack can be used to show termination of the current flight path. This study discusses and compares both of these methods.

10.2.9 Hamilton, V. E. and Benson, J. A. A Commentary on the Problems of Optical Presentations in Aircraft Cockpits, paper presented at the International Air Transport Association 15th Technical Conference, Lucerne, Switzerland, April 1963. Engineering Paper No. 1583, Douglas Aircraft Company, Long Beach, California, 1963.

This paper is probably the best short and authoritative summary available on optical systems and their implementation in head-up displays (according to Jenney, et al, pg 11-44, cited above, para. 10.2.3).

10.3 Large-Screen Displays

Several of techniques described in previous sections are suitable for displays larger than console size intended for viewing by groups of people ranging from a few individuals to the audience of a drive-in movie. Large-screen display techniques are reviewed in the following documents.

10.3.1 Thomas, P. G. Large-Screen Displays. Space/Aeronautics, May 1967, 82-91.

Thomas describes some of the uses of large-screen displays in military command-and-control systems and reviews the status of display technology. Included is a table of performance parameters for plotting boards, storage projectors, light valves lasers, and matrix-addressed (thermoplastic, LED and EL) displays.

10.3.2 Mahan, R. E. A State-of-the-Art Survey of the Data Display Field. BNWL-725, Pacific Northwest Laboratory, Richland, Washington, May 1968.

Large-screen display technology is discussed in this survey document (p. 22-32). Techniques described include: projection displays (film, CRT, slides) electrostatic displays (thermoplastic and light valves), laser displays, magneto-optical displays, and 3-D displays.

10.4 Flat Panel Displays

Flat panel display technology is reviewed in the following documents.

10.4.1 Zinn, M. H., and Schlam, E. Flat Panel Displays R&D Technical Report ECOM-3045, U.S. Army Electronics Command, Fort Monmouth, N. J., December 1968.

The common military need to conserve volume and weight has resulted in considerable emphasis on the development of flat panel displays to replace the deep cathode ray tube. Many approaches to this problem are described in this paper, including a flat CRT which is under development at USAECOM. The latter approach is based on a trade-off of the large throw-distance required in the conventional CRT for complexity of a matrix address system.

10.4.2 Kallin, G. R. Flat Panel Matrix Displays - An Overview. Proc. of the S.I.D. Vol. 12/1 First Quarter 1971, 8-15.

In this review of flat panel technologies, Kallin finds most of them non-viable. Only light-emitting diodes and plasma displays are found generally suitable by his analysis. He regards them both as clearly displays of the seventies.

10.4.3 Goede, W. F., Jeffries, L. A. and Gunther, J. E. A New Flat Panel Alphanumeric Display, the Digisplay. IEEE 70C55-ED paper presented at the 1970 IEEE Conference on Display Devices in New York City, December 2-3, 1970.

The Digisplay is a digitally addressed electron beam scanning device under development by Northrup. Characters are formed in a 5 x 7 dot matrix. This paper discusses its advantages and principles of operation.

10.5 Integrated Display Systems

The Joint Army-Navy Aircraft Instrumentation Research (JANAIR) Program has sponsored basic and applied research concerned with advanced instrumentation systems. A concept of integrated aircraft displays that present pictorial representations of the real world emerged from this research and continues to be actively investigated as display technology changes. Some of these research programs and related efforts are described in the following documents.

10.5.1 Dersch, W. E. and Johnson, R. T. Computer-Managed Display System for Advanced Commercial Transports. Paper presented at the NASA symposium on Recent Advances in Display Media held in Cambridge, Mass., September 19-20, 1967. NASA SP-159, 1968.

Describes several integrated displays proposed as part of an automatic flight management system. This is a Boeing concept of an advanced display system.

10.5.2 Magruder, W. M., Gorham, J. A., and Livingston, R. F. Developments Associated with Advanced Commercial Aircraft Crew Requirements. AIAA Paper No. 67-399 presented at AIAA Commercial Aircraft Design and Operation Meeting held in Los Angeles, California, June 12-14, 1967.

This paper describes Lockheed's systems engineering approach to design and the resulting advanced display system considered for an SST aircraft.

10.5.3 Murphy, J. V. et al. Integrated Cockpit Research Program, Volume I (AD 662 185) and II (AD 662 186). Litton Guidance and Control Systems Division, Woodland Hills, California, January 1967.

Describes a JANAIR sponsored program to identify the goal of advancing state-of-the-art for cockpit controls and displays through cockpit integration research.

10.5.4 Zipoy, D. R., et al. Integrated Information Presentation and Control System Study USAFL HFFDL-TR-70-79. Volume I, System Analysis. Volume II, System Development Concepts' Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, August 1970.

Report of a study conducted by Boeing to develop an integrated cockpit concept for a tactical fighter of the 1975-1980 time period. On the basis of a detailed analysis (Volume II) of requirements, desired characteristics are defined for cockpit displays (Volume I).

10.5.5 Wooding, H. C. et al. Integrated Vertical Display Research. AD 709 460. United Aircraft Corporation, Norwalk, Conn., July 1970.

Describes a JANAIR sponsored research program to develop aircraft performance criteria based on military requirements for 1970-1975 time period and to define recommendations for an integrated electronic vertical display. Several display design guidelines for the use of CRT's for this purpose are included (p.4-1 and 4-2).

10.5.6 Carel, W. L. Pictorial Displays for Flight. AD 627669. Hughes Aircraft Company, Culver City, California, December 1965.

This document is the final report of a JANAIR study to examine the potential of raster scan pictorial displays for aircraft application. The study was restricted to four mission segments for one- or two-place aircraft: take off; climb out; point-to-point navigation; and landing. Both horizontal and vertical situation displays are evaluated.

10.5.7 Crook, M. N., Roben, M. W., and Wade, E. A. Trends and Developments in Visual Displays. Tufts University Human Engineering Information and Analysis Service, HEIAS Rep. No. 107, December 1967.

This paper contains a brief survey (p. 28-41) of pictorial displays used in aircraft and submarines.

10.5.8 Ketchel, J. M. and Jenney, L. L. Electronic and Optically Generated Aircraft Displays. A Study of Standardization Requirements. JANAIR Report No. 680505 prepared by the Matrix Corporation, May 1968.

This report is basically a summation of the results of a review of research literature pertaining to electronic and optically generated displays. Information requirements, symbology and format, and display characteristics are the central topics of the study. Specific conclusions and recommendations are given at the end of the report (p. 285-308).

10.5.9 Van Houtte, N. A. J. Display Instrumentation for V/STOL Aircraft in Landing. Sc. D. Thesis, M.I.T., Cambridge, Mass., June 1970.

This study investigated a perspective contact-analog display for use in STOL aircraft. Experiments were conducted to determine: the information needed by a pilot landing a STOL aircraft; how approach procedures can be modified by improved displays; and the impact of improved displays on aircraft noise, etc.

10.6 Predictive Displays

Although predictive displays may be pictorial in format and thus subsumable under the preceding topic, the following warrant a separate listing.

10.6.1 Warner, J. D. A Fundamental Study of Predictive Display Systems. NASA study, CR-1274, conducted at the University of Michigan, Ann Arbor, Michigan, February 1969.

After a review of the known literature of the subject and a discussion of the characteristics that are important in any predictive system an experimental investigation was conducted of three display forms (exploratory prediction, on-line prediction, and no prediction). A general conclusion is that predictive displays are potentially useful whenever the information processing requirements are severe and required mental prediction time spans are not short.

10.6.2 Rouse, W. B. An Application of Predictor Displays to Air Traffic Control Problems. M. S. Thesis, M.I.T., Cambridge, Mass., September, 1970.

This study evaluated the feasibility of using a predictor display system to help solve terminal area air traffic control problems. A computer-based predictor display was evaluated as an aid for the air traffic controller in guiding aircraft to the glidepath.

10.7 Map Displays

The following paper by Jim McGrath adequately covers this topic.

10.7.1 McGrath, J. J. Contemporary Map Displays. Paper presented at the AGARD conference on Guidance and Control Displays at Paris, France, October 19-21, 1971. AGARD-CP-96, February 1972.

This paper presents a general review of developments and capabilities in airborne map-display systems and summarizes some of the current problems in their design and use.

10.8 Touch Displays

The original concept of the touch display, devised by E. A. Johnson, made use of an operator's finger contact on a "touch wire" to unbalance an inductance capacitance bridge. The resulting signal could actuate a digital computer. A touch display coupled to a computer can be treated as a keyboard in which the labelling of the keys is varied by computer program as required. A touch display therefore combines the functions of keyboard and display. Technical details of the touch display are described in Johnson's paper listed below. An attempt at evaluation is described in the paper by Hopkin.

It should be noted that the concept of touch displays is quite different from that of tactile displays which are discussed in the following section (10.9).

10.8.1 Johnson, E. A. Touch Displays: A Programmed Man-Machine Interface. Ergonomics, 1967, 10(2), 271-277.

10.8.2 Hopkin, V. D. The Evaluation of Touch Displays for Air Traffic Control Tasks. Paper presented at the Conference on Displays sponsored by the Institution of Electrical Engineers and held at the University of Technology, Loughborough, England, September 7-10, 1971.

10.9 Tactile Displays

Although tactile sources of stimulation, such as vibration, have been used in aircraft for a long time, their use has been nominal when compared with visual displays. However, tactile displays recently have received widespread interest as aids to the blind and a voluminous literature has resulted from widespread research efforts. The following papers are representative of this interest.

10.9.1 Noll, A. M. Man-Machine Tactile Communications. SID Journal, vol. 1, no. 2, July/August 1972.

This paper describes a three-dimensional tactile device by means of which a person can "feel" a three-dimensional object that exists only in the memory of a computer. Test results suggest that tactile man-machine communication is useful for "depicting" surfaces and objects which would be virtually impossible to display visually.

10.9.2 Hill, J. W. A Describing Function Analysis of Tracking Performance Using Two Tactile Displays. IEEE Transaction on Man-Machine Systems, March 1970, 92-100.

A display consisting of two vibrators attached to the body was tested together with a novel ripple display consisting of seven sequentially activated air-jet stimulators. The ripple display was found better than the vibrator display and it produced operator time delays shorter than those measured with visual displays.

10.9.3 Bliss, J. C. A Provisional Bibligraphy on Tactile Displays. IEEE Transactions on Man-Machine Systems, March 1970, 101-108.

10.9.4 Ross, D. H., et al. Tactile Display for Aircraft Control. Sanders Associates, Inc., Nashua, New Hampshire, January, 1973.

Reviews development of tactile displays suitable for flight control.

10.10 Auditory Displays

Auditory displays present information in the form of sound for processing by the hearing sense. In many cockpit situations auditory, or acoustic displays as they are sometimes called, are clearly superior to visual displays. Their most common use is for warning purposes when immediate attention or action is required but they are also used when vision is overloaded or degraded due to illumination level, vibration, acceleration, or other environmental factors.

The types of sounds used in auditory displays include pure tones, noise makers such as buzzers, bells, horns, sirens, etc., or voice. Tones or noise signals are used when the message is extremely simple, when speech communication channels are overloaded or degraded. Tones are also used to transmit other types of information such as in sonar or radio range systems.

The voice mode of auditory display may involve the selection and playback of pre-recorded messages or the generation of synthetic speech. One promising synthetic voice display is a unit developed by Advanced Communications Incorporated, now being handled by the McDonnell Douglas Electronics Company. This device, which uses solid state circuitry for control and generation of synthetic speech, has no apparent limitation on potential vocabulary and offers greater reliability and vlexibility than magnetic tape.

The flexibility of synthetic speech techniques makes possible many new or improved applications of auditory displays such as: very specific verbal warnings and directions; verbal checklists; verbal feedback; and verbal data link. These potential applications, as well as other aspects of auditory displays, are discussed in the DAC technical proposal listed below with other sources of information on this topic.

10.10.1 Definition of Auditory Displays for Vehicular Systems. Technical Proposal 72D-051, Douglas Aircraft Company, Long Beach, California, 11 February 1972.

This proposal reviews the development and current status of auditory displays, describes perceptual factors in their use, and discusses their posential applications.

10.10.2 Licklider, J. C. R. Audio Warning Signals for Air Force Weapon Systems. USAF: WADD-TR-60-814. Wright Air Development Division, Wright-Patterson AFB, Ohio. March, 1961.

This report presents technical information on the design, selection, and use of audio warning signals. It describes a procedure for specifying the acoustical characteristics of warning signals required for conditions expected in Air Force ground-based, airborne, or spaceborne systems.

10.10.3 Katz, D., Emery, J. A., Gabriel, R. F., and Burrows, A. A. Experimental study of Acoustic Displays of Flight Parameters in a Simulated Aerospace Vehicle. Douglas Aircraft Company Report, LB 32838. Long Beach, California, 1965.

Katz, et al. studied the use of auditory displays in target detection and for displaying flight parameters. Lateral target location was coded by a 500 Hz tone that indicated direction through binaural intensity and phase differences. The auditory display proved superior to a visual display in terms of target location performance. Other auditory displays tested included a binaural intensity cue for roll angle and an angle of attack display using frequency and wave form. Comparisons with a visual display indicated the auditory displays led to performance as good or better than with the conventional visual displays.

10.10.4 Abbott, P. E. and Woodbury, J. R. Joint Army-Navy Aircraft Instrumentation Research Investigation of Auditory Displays. Douglas Aircraft Company Report 32125. Long Beach, California, January, 1965.

This study examined the use of auditory displays for aircraft carrier landing. Among the issues investigated were: (1) audibility of various frequency and intensity combinations in the presence of a masking jet noise; (2) the relative

performance among aircraft control modes (throttle versus stick for speed); and (3) a comparison of visual and auditory displays (with and without quickening) during simulated carrier landings. Results were favorable for the use of auditory displays, alone or in combination with visual displays.

10.10.5 Kemmerling, P., Gliselhart, R., Thorburn, D. E., and Cronburg, J. G. A Comparison of Voice and Tone Warning Systems as a Function of Task Loading. USAF: ASD-TR-69-104. Aeronautical Systems Division, Wright-Patterson AFB, Ohio, September, 1961.

Evaluated voice and tone warning systems by comparing pilots' visual scan patterns and response times under various task load and saturation conditions. It was found that pilots who received tone warnings were forced to check the annunciator panel when receiving a non-critical failure. The voice warning afforded the pilot the option of responding to or completely ignoring a failure based on mission requirements. Voice-warned pilots who chose to respons to the failure did so with faster response times than pilots receiving tone warning.

10.10.6 Simon, J. R. and Croft, J. L. Communicating Directional Information with an Auditory Display. Journal of Applied Psychology, 1971, 55 (3), 241-243.

This study was concerned with determining whether right or left commands could be communicated more effectively using symbolic, directional, or combined directional and symbolic cues. Directional cues (pure tone presented to either left or right ear) were found to be far more effective than symbolic cues (two frequencies of a pure tone presented to both ears).

10.10.7 Flanagan, J. L. The Synthesis of Speech. Scientific American, February, 1972, 48-58.

Describes the composition of speech sounds and reviews the development of mechanical and electronic speech synthesizers.

10.10.8 Morgan, C. T., Cook, J. S., Chapanis, A., and Lund, M. W. Human Engineering Guide to Equipment Design. New York: McGraw-Hill Book Company, 1963.

10.10.9 Woodson, W. E., and Conover, D. W. Human Engineering Guide for Equipment Designers. Los Angeles: University of California Press, 1964.

11. HUMAN FACTORS DATA SOURCES

There is no convenient repository but there is a wealth of human factors data pertaining to display design available in many documents. Some promising sources are listed below but it may take time, patience, and a cynic's eye, to isolate useful information in some of these documents.

11.1 Pfeiffer, M. G., Clark, W. C., and Danaher, J. W. The Pilot's Visual Task: A Study of Visual Display Requirements. Technical Report: NAVTRADEVCEN 783-1, prepared by Courtney and Company, Philadelphia, Pa., March 1963.

This study analyzes the visual world of the pilot and identifies information requirements for various flight tasks.

11.2 Burnette, K. T. The Status of Human Perceptual Characteristic Data for Electronic Flight Display Design. Paper presented at AGARD conference on Guidance and Control Displays held in Paris, France, October 19-21, 1971. AGARD-CP-96, October, 1971.

This paper summarizes the results of a literature search conducted by Manned System Sciences, Inc. which is reported in the following document.

11.3 Semple, C. A., Heapy, R. J., and Conway, E. J. Analysis of Human Factors Data for Electronic Flight Display Systems. USAF: AFFDL-TR-70-174. Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, April 1971.

This report presents the results of a review by Manned System Sciences, Inc. of 1178 technical documents dealing with human factors considerations in electronic flight display systems. Many tables of quantitative data are presented for topics such as: information coding; visual acuity; CRT display resolution; flicker; and environmental variables.

11.4 Barmack, J. E. and Sinaiko, H. W. Human Factors Problems in Computer-Generated Graphic Displays. Study S-234 conducted by the Institute for Defense Analysis, Washington, D.C., April 1966.

11.5 Gould, J. D. Visual Factors in the Design of Computer-Controlled CRT Displays. Human Factors, 1968, 10(4), 359-376.

A difficulty that plagues attempts to develop general conclusions about visual design problems is the fact that each visual variable interacts with other visual variables so that no variable is independent. Gould tries to avoid this difficulty by considering one variable at a time, specifying a range of recommended levels for that variable, and then limiting discussion of subsequent variables to the specified ranges of already discussed variables.

11.6 Poole, H. H. Fundamentals of Display Systems. Washington: Spartan Books, 1966.

Chapter 15, pages 275-295, contains a description of human factors relevant to display design.

11.7 Sherr, S. Fundamentals of Display System Design. New York: Wiley-Interscience, 1970.

In Chapter 1, pages 1-52, Sol Sherr describes various parameters and human factors that are basic considerations for display design.

11.8 Meister, D. and Sullivan, D. J. Guide to Human Engineering Design for Visual Displays. AD 693 237. The Bunker-Ramo Corporation, Canoga Park, Calif., 30 August 1969.

This guide is intended to serve as a source of basic data on human capabilities and performance for use by display engineers. In its preparation a review was made of all available literature (over 600 documents) describing the human factors that affect display design.

11.9 Hopkin, V. D. Human Factors in the Ground Control of Aircraft AGARD document AG-142-70, April 1970.

11.10 Stenson, H. H. Human Factors in the Design of Electroluminescent Displays for Aerospace Equipment. USAF: AMRL-TR-66-130. Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio, September 1966.

11.11 Synder, T. A. and McTee, A. C. Human Engineering for the Air Force Control-Display Program, USAF: AFFDL-TR-72-109. Air Force Flight Dynamics Laboratory, Wright Patterson AFB, Ohio, June 1972.

Describes the research program conducted in support of the Air Force Integrated Flight Control-Display Program.

12. COCKPIT LIGHTING

The effects of cockpit lighting on vision have been investigated in many research programs. A few sources of data on this problem are listed below.

12.1 AGARD. Aircraft Instrument and Cockpit Lighting by Red or White Light. Symposium held in Rhode-Saint-Genese, Belgium, October 30-31, 1967. AGARD-CP-26, October 1967.

12.2 Bauer, R. W. Night Flying Vision. I. TM 12-68, Research Problems and Methods. II. TM 13-68, Psychophysical Comparisons of Three Colors of Cockpit Lighting. Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, October 1968.

12.3 Reynolds, H. N. The Visual Effects of Exposure to Electroluminescent Instrument Lighting. Human Factors, 1971, 13(1), 29-40.

This paper was described above (5.8) in conjunction with EL displays.

13. DISPLAY DESIGN GUIDES

In addition to design guidance documents already described, e.g. the papers on integrated displays and human factors, the documents listed below deal with the general problem of design or with specific design areas.

13.1 Devoe, D. B. Toward an Ideal Guide for Display Designers. Human Factors, 1963, 5(6), 583-591.

Discusses requirements for an ideal design guide and estimates the feasibility of making a first approximation toward that goal.

13.2 Hornyak, S. J. Effectiveness of Display Subsystem Measurement and Prediction Techniques. AD 821 142. Bunker-Ramo, Canoga Park, Calif., September 1967.

This report describes methods whereby the characteristics of display subsystems may be evaluated.

13.3 Singleton, W. T. Display Design: Principles and Procedures. Ergonomics, 1969, 12(4), 519-531.

Describes the advantages and limitations of three general approaches to display design: use of checklists; use of formal procedures; and use of behavior theory. A sample checklist is included.

13.4 Roscoe, S. N. Airborne Displays for Flight and Navigation. Human Factors, 1968, 10(4), 321-33.

13.5 Johnson, S. L. and Roscoe, S. N. What Moves, the Airplane or the World? AD 713 179. Aviation Research Laboratory, University of Illinois, Savoy, Illinois, June 1970.

13.6 Wierwille, W. W. A Diagrammatic Classification of Man-Machine System Displays. Human Factors, 1964, 6(2), 201-207.

Describes the construction of a diagram for the classification of displays on the basis of complexity of instrumentation. The author believed the diagram could provide guidelines that are helpful in gaining a better understanding of display design concepts and in selecting displays for a given man-machine system.

13.7 Munns, M. Recent Research Applicable to the Design of Electronic Displays. Perceptual and Motor Skills, 1972, 34, 683-690.

Aside from the fact that the "recent" literature reviewed in this paper has a mean age of 8-3/4 years and a range of 4-12 years, it is of interest to note the author's comment that the author of a display guide should advisedly prescribe with "tongue in cheek".

14. DISPLAY STANDARDS AND SPECIFICATIONS

Military standards and specifications that relate to electronic and optically generated displays are listed in Appendix A of the following document.

14.1 Ketchel, J. M. and Jenney, L. L. Electronic and Optically Generated Aircraft Displays. A Study of Standardization Requirements. JANAIR Report No. 680505 prepared by the Matrix Corporation, May 1968.

15. TERMINOLOGY

The following documents contain moderate to extensive listings of display terminology.

15.1 Ketchel, J. M. and Jenney, L. L. (See 14.1 above for title). Appendix B (p. B1-B29)

15.2 LaSalle, R. H. A Summary of Terminology and Criteria Employed in Image Quality Assessment and Specification. Technical Report No. RADC-TR-67-578. Rome Air Development Center, AFSC, Griffiss AFB, New York, December 1967.

15.3 Meister, D. and Sullivan, D. J. Guide to Human Engineering Design for Visual Displays. AD 693237. The Bunker-Ramo Corporation, Canoga Park, California, 30 August 1967.

15.4 Poole, H. H. Fundamentals of Display Systems. Glossary. Washington: Spartan Books, 1966.

15.5 Sherr, S. Fundamentsl of Display System Design. Glossary, p. 433-443. New York: Wiley-Interscience, 1970.

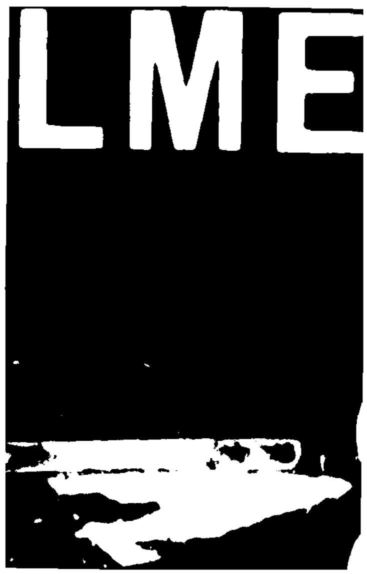
15.6 Sherr, S. Standards and Definitions Report. SID Journal, 1972, November-December, 18-19.

This is a glossary of terms and definitions for industrial cathode ray tubes.

16. DISPLAY EQUIPMENT MANUFACTURERS

Manufacturers of information display equipment in 33 major information product categories are listed in the following document.

16.1 Information Display Buyers Guide 1971. Los Angeles: Va[illegible] Engineering Publications, Inc., 1971.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